HYPERSPECTRAL TECHNOLOGY TRANSFER TO THE U.S. DEPARTMENT OF INTERIOR: SUMMARY OF RESULTS OF THE NASA/DOI HYPERSPECTRAL TECHNOLOGY TRANSFER PROJECT

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1. Abstract

In 1997 the Office of Biological Informatics and Outreach (OBIO), Biological Resources Division, U.S. Geological Survey and NASA, Office of Earth Science (OES), initiated a coordinated effort for applying Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data and analysis, as a technology transfer project, to critical DOI environmental issues in four study sites throughout the United States. This work was accomplished by four U.S. Department of the Interior (DOI) study teams with support from NASA/OES principal investigators and the Office of Earth Science programs. The studies, including personnel, objectives, background, project plans and milestones were documented in a project website at <http://biology.usgs.gov/hwsc>. This report summarizes the final outcomes of the project, detailing accomplishments, lessons learned, and benefits realized to NASA, the U.S. Geological Survey, and the participating DOI bureaus.

2. Introduction and background

A project steering committee was formed in early 1997 consisting of NASA and USGS scientists and representatives of four DOI bureaus. In April 1997 the committee solicited proposals from DOI bureaus for studies relating to current DOI initiatives that addressed significant environmental issues from several diverse ecosystem areas that could benefit from application of hyperspectral imaging technology.

Descriptions of these study sites including personnel, objectives, background, project plans, milestones and first and second year status reports (Getter and Wickland, 1998, Root and Wickland, 2000) were posted on a website produced specifically for this project <http://biology.usgs.gov/hwsc>. This report summarizes the three-year project with a final synopsis of accomplishments, lessons learned, and benefits realized by participating DOI bureaus.

The goals of this undertaking, as originally developed by the project's steering committee were: (1) Provide DOI technical and resources management personnel information and technical assistance on hyperspectral systems and advanced technologies, (2) Focus on a limited number of resource issues or problems of interest to DOI that could potentially be addressed using hyperspectral remote sensing technologies, and (3) Use workshop formats and partnerships for introducing DOI resource and line management personnel to hyperspectral technologies, and to evaluate the results of the four pilot studies.

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These studies were conducted only with funds and/or resources committed by the participating bureaus. Studies were selected on the basis that baseline information pertinent to each of the studies proposed was already well developed and readily available. NASA contributed AVIRIS missions for each of the selected sites, and provided technical assistance both directly and through partnering organizations.

In July 1997, the selected DOI and NASA Principal Investigators held an organizational workshop in Denver, Colorado to discuss each study. Work plans were devised to include description of the area, existing baseline data, ancillary data collection efforts, analysis capability, knowledge of the technologies involved, milestones to be achieved, resource availability, logistics and expectations. Robert Green, NASA/JPL provided an overview of the AVIRIS platform, hardware, software and analysis capabilities along with an appreciation for flight planning logistics. The outcome of the workshop was construction of a framework enabling the DOI and NASA PI's to develop implementation plans defined well enough to carry out those activities necessary for the data collection, analysis and evaluation of hyperspectral technology on their respective environmental parameters to be measured. Planning efforts on flight line parameters were sufficiently developed so that information could be transmitted to the NASA Airborne Science and Applications Program flight control group for mission planning for 1998 and 1999.

3. Information transfer

The entire project, including all technical and logistical aspects, has been documented by two published progress reports (Getter and Wickland, 1998, Root and Wickland, 2000), and by establishment of a project web site documenting the entire project history and accomplishments <biology.usgs.gov/hwsc>. The contents of this page consists of the steering committee membership list, the four implementation plans, a hyperspectral imaging searchable bibliography, a list of 200 URL's with hyperspectral information, links to the USGS Spectroscopy Lab, NASA AVIRIS Data Facility, AVIRIS flight line map and some University and vendor sites. It is the intent to use this page as a vehicle for communication to interested parties regarding these study efforts and outcomes. It is also anticipated that results of the research for each of the studies will be published in appropriate venues in the scientific literature by each of the respective teams of principal investigators.

As a method for porting the technology to the DOI/Bureau technical line manager, a second workshop, jointly sponsored by NASA and the DOI was proposed to convert the experience gained in these selected studies into a forum that would provide for a tutorial of the advanced systems covering: 1) characterization of hyperspectral hardware and software systems, 2) characterization of hyperspectral data, 3) exploitation and expectations of the data, and 4) data fusion techniques, degrees of difficulty encountered, and known successes and failures in the use of the data and/or technology. Unfortunately funding limitations did not permit the implementation of this last element of the technology transfer project.

4. Summary of study sites

A summary of each of the four study sites is provided below including the personnel involved, objectives, and brief background information. Accomplishments, benefits to DOI land managers and study site partners, and lessons learned are discussed.

Study site 1 - Mapping vegetation alliances, Congaree Swamp National Park (COSW), South Carolina.

Personnel:
PI's: Mike Story of the National Park Service and Dr. Mary Martin, University of New Hampshire.

Objectives:
The primary objective of this project is to incorporate the use of AVIRIS imagery with existing aerial photography and field collected vegetation data in order to evaluate the ability of the AVIRIS data to accurately map the variety of tree species found at COSW.

Background:
The COSW project includes approximately 30,000 acres of old-growth forest just Southeast of Columbia, SC. It contains a complex mosaic of wetland and upland communities. COSW is subjected to occasional hurricanes that can cause severe destruction to these communities. An important element of the NPS mission to manage the resources at COSW includes understanding the complex relationships of these communities and the changes that occur as a result of the destructive winds.

Accomplishments:
Low altitude AVIRIS data were acquired October 24, 1998 during fall leaf change, which is an ideal time to optimize species distinction. High altitude AVIRIS data were also acquired on May 17, 1999. Limited field spectra were obtained in July, 1998. Color composites of selected bands and 3-color composites of selected principal components show strong spectral contrasts. Detailed forest canopy texture is visible in the low altitude data. Preliminary spectral analysis of both low and high altitude data sets have yielded very promising results for mapping at the vegetation alliance level, and in some cases the species level.

Benefits realized to DOI land managers and study site partners:
These data are helping land managers at Congaree Swamp better understand the complexity of the distribution of old growth tree species within the park and NPS personnel are gaining experience in hyperspectral imaging analysis.

Lessons learned:
Hyperspectral characteristics of AVIRIS can contribute to the understanding and mapping of species and vegetation associations. However, multidirectional geometric anomalies of up to 2 to 3 pixel widths, which were found in both the low and high altitude data are inhibiting use of the data for mapping purposes. Both scenes were found to contain non-systematic geometric characteristics that cannot be eliminated via traditional registration techniques.

Study site 2 - Estimating the effect of invasive woody species on grasslands, Great Plains Basin.

Personnel:
PI's: Dr. Dave Meyers, B. Wylie, M. Choate, US Geological Survey, EROS Data Center and Dr. Carol Wessman, University of Colorado with The Nature Conservancy, Augustana College, North Dakota State University, the University of Toronto, the University of Nebraska, and Oklahoma State University.

Objectives:
The objective of this study is to use spectral signature analysis and linear spectral mixing models to determine the degree to which a grassland spectral signature is influenced by woody species. Ultimately, these results will provide a means to quantify species gradients, allowing the isolation of the woody components in land cover mapping over the grasslands.

Background:
The focus of this study is to investigate the effectiveness of AVIRIS for mapping the encroachment of woody species on grasslands in the Great Plains. Several test sites, owned by the Nature Conservancy, were chosen to map specific invasive plants: Tallgrass Prairie Preserve (OK) and Konza Prairie Preserve (KS) for mapping oak and juniper species, and the Niobrara Valley Preserve (NE) for mapping sumac and juniper species. The preliminary work reported here focuses on the Niobrara site, because the intermixing of eastern red cedar with ponderosa pine poses a particularly difficult spectral discrimination problem.

Accomplishments:
The 1999 data acquisition season was highly productive, with extensive ER-2 (high altitude) coverage over all three sites (Niobrara on 7/7/1999, Tallgrass on 7/13/1999 and 7/19/1999, and Konza on 7/13/1999), and multiple Twin Otter (low altitude) visits to Niobrara (7/22/1999 and 11/11/1999). Work began on the 7/22 low-altitude acquisition at Niobrara, because necessary geolocation information was missing from the other acquisitions that are required for identifying GPS measured reference points in the imagery. An agreement with JPL will give us access to geolocation information in the future, allowing us to (1) reproduce the JPL geocoding technique, and (2) add terrain correction to the JPL method to remove site-specific geometric artifacts.

The 7/22 low-altitude AVIRIS data at Niobrara was used to develop several methods for discriminating the eastern red cedar (a juniper) from ponderosa pine. The georectified data were corrected for atmospheric effects using ATREM, bands associated with water vapor and ultraviolet ozone absorption were removed, and a minimum noise fraction (MNF) transformation within ENVI (Environment for Visualizing Images) was applied to prepare the data for analysis. For our purposes, an MNF threshold of 2.0 was chosen, yielding 23 MNF bands.

The first analysis followed the "spectral endmember" approach: (1) find "pure" pixels, (2) identify endmember via "n-dimensional visualization" tools, identify endmembers then perform unmixing. Up to 40,000 iterations of the "pixel purity index" algorithm was run in an attempt to find endmembers associated with the different species, without success. We attribute this failure largely to our inexperience with hyperspectral data, coupled with the difficulty in separating juniper from pine as endmembers. In another approach, field training sets of different woody types (juniper, pine, deciduous and sumac) were used in a "matched

filtering" scheme on MNF transformed data. Errors of omission and commission were reasonable using this approach.

A third approach, employing decision trees, met with considerable success, the results of which were presented at the Ninth JPL Airborne Science Workshop (Wylie et al., 2000). This uses hyperspectral data in a manner similar to the classification techniques used to generate the Multiresolution Land Cover (MRLC) classification, with considerable success.

We look forward to analyzing the 11/11/1999 acquisition, because the deciduous leaves were off at that time, exposing the junipers under the canopy. This is a common propagation method for the junipers: develop in the understory, then spread into the grasslands. Also, the junipers dried down more rapidly than the ponderosas, causing a significant color difference between the two species. This provides ideal conditions for identifying junipers distinctly from pines.

Future plans: (1) develop precision corrections for ER-2 and Twin Otter, (2) complete the 7/22 analysis, (3) analyze the 11/11 data, (4) analyze the ER-2 data, (5) post-validation of results.

Benefits realized to DOI land managers and study site partners:
Ability to remotely distinguish between exotic eastern red cedar and native ponderosa pine is of significant value to a variety of Great Plains land managers committed to monitoring and/or controlling increasing populations of invasive eastern red cedar.

Lessons learned:
End-member pixel unmixing analysis appeared to have limited usefulness for separating eastern red cedar from ponderosa pine, possibly because of the study team's inexperience with the technique, but more likely because of the closeness of their spectral signatures.

Matched filtering and the MRLC decision tree classification techniques both appear to be effective for separating eastern red cedar and ponderosa pine.

In order to effectively validate classification results, geocoding techniques applied to AVIRIS data need to be refined to handle localized geometric artifacts and provide for terrain correction.

Study site 3 - Identify and map leafy spurge infestations, Theodore Roosevelt National Park, North Dakota

Personnel:
PI's are Dr. Ralph Root, U.S. Geological Survey, Steve Hager, Theodore Roosevelt National Park, Dr. Gerald Anderson, Agricultural Research Service, Dr. Susan Ustin, Dr. Pablo J. Zarco-Tejada, Michael O'Neill, and Geogre Scheer, University of California – Davis.

Objective:
The objective of this project is to determine the extent to which hyperspectral imaging can be used to develop automated methods for detecting and mapping the extent of leafy spurge (*Euphorbia esula L.*) infestations in Theodore Roosevelt National Park

Background:
Leafy spurge (*Euphorbia esula L.*) is a troublesome invasive non-native plant on the Northern Great Plains of the United States. Current research shows that leafy spurge is a

serious invader into the south unit of Theodore Roosevelt National Park near Medora, North Dakota. This aggressive invasion has displaced many native plant species. In addition to destroying the rich species diversity unique to the badlands, significant ecological impacts are resulting. Infestations have grown from 13 ha. in 1972 to an estimated 702 ha. in 1993, 4% of the park's 18,680 ha. land base. Currently, leafy spurge is the number one resource threat to the park and environs. The Resource Management Plan of Theodore Roosevelt National Park identifies a requirement of intensive management to reduce and contain these infestations in keeping with the "preserve and protect" mandate of the National Park Service.

Accomplishments:
Low altitude AVIRIS data were acquired in October, 1998 and high altitude AVIRIS data were acquired in July, 1999. Ground calibration and field spectra were collected in support of both data collection events. Leafy spurge has been successfully extracted from the 1999 data by spectrum matching to minimum noise fraction components employing the ENVI spectral angle mapper algorithm using carefully selected training spectra from a calibrated version of the imagery (O'Neill et al., 2000). Initial analysis covered a two-cube data set selected from one of the four 1999 AVIRIS flight lines. Further work will extend this analysis to all four flight lines covering the entire south unit of the park. Results will be validated via a quantitative accuracy assessment using ground data delineated by sub-meter global positioning systems. An initial accuracy assessment revealed difficulties with consistent geo-positioning on both the AVIRIS data and photo-interpreted verification data, making quantitative accuracy assessment a problematic issue. Future studies will examine refinements in orthorectification to bring geo-locational error to less than +/- 1 pixel (17 m).

Benefits realized to DOI land managers and study site partners:
The initial study team introduced some new technologies to address the park's top priority resource management problem, which is controlling highly aggressive leafy spurge infestations. As a result of this study, the park's visibility in the scientific community has been elevated as its challenges in managing leafy spurge are communicated to many of the nation's leading remote sensing specialists. Partners involved in the study are learning a valuable and potentially effective new technology for invasive species management. An additional by-product of this study was the development of the Spectral Analysis Management System (SAMS) by the Center for Spatial Technologies and Remote Sensing at UC Davis. SAMS permits a user to browse, sort, and analyze/combine large numbers of ground spectra in support of hyperspectral image analysis.

Two additional studies have been spawned as a result of the current study. Detection and mapping of leafy spurge using orbital hyperspectral imaging in comparison with AVIRIS was selected as one of three invasive plant studies on NASA's EO-1 Validation Team. A second high altitude AVIRIS mission will be flown over the park in 2001 as a part of this study. A more regional study, sponsored by TEAM (The Ecological Area-wide Management) Leafy Spurge in North Dakota <http://www.team.ars.usda.gov/> is comparing the cost effectiveness of a cross section of remote sensing techniques and scales for mapping leafy spurge annually on a regional basis. Two Ph.D. studies also developed as an outcome of the original study. The first will develop an expert system that models environmental factors controlling the occurrence of leafy spurge to predict likely areas for future infestation. The second will produce park-wide leafy spurge maps from both the 1999 and 2001 AVIRIS data sets, conduct change detection between the two, and relate cause/effect of the changes

with spatially documented leafy spurge control measures compiled by the park since the mid-1990's. A master's thesis study has also started in 2001 that will analyze the 1999 AVIRIS data for development of a fire fuels map over the park. Yet another study will be started in 2001 by the USGS to analyze the 1998 and 1999 AVIRIS data for mineralogical characteristics of geological formations related to burnable coal seams in the park.

Lessons learned:
Field activities in support of hyperspectral imaging are costly in terms of equipment, people, and time required. Because of the need to be in the field at the time of aerial data collection, effective planning and coordination of fieldwork is critical. The timing of overflights in relation to growing season characteristics and field crew logistics are vital to successful data collection.

The study team found that having a state-of-the-art well equipped geospatial laboratory on-site was extremely valuable for nightly downloads and near real-time review/evaluation of ground data collected each day.

The study team's first attempt at constructing a quantitative accuracy assessment revealed geo-locational problems in both the AVIRIS data and in the manually interpreted verification data. This underscores the importance of developing consistent and accurate geo-positioning in AVIRIS missions if the data are to be effectively used for mapping applications and merged with other types of geodata in land manager's GIS data bases.

The project, especially in its early stages, frustrated park managers as things did not happen any faster than they did, in the context of a time-sensitive and pressing resource problem. As the project evolved and promising results emerged, the relation between pragmatic time sensitive management needs and the characteristic longer-term nature of research came into perspective. The two additional studies and 3 student research projects that grew from the initial technical transfer study has created an ongoing research program in the park that will continue to provide information and guidance to managers far beyond the original scope of the NASA/DOI study.

Study site 4 - Mapping of mercury-containing mineral sources in the Owyhee Reservoir watershed, Oregon

Personnel:
PI's Ron Pearson, Douglas Craft, and David Zimmer, Bureau of Reclamation, Dr. Roger N. Clark, U.S. Geological Survey, and Paul Seronko, Bureau of Land Management

Objectives:
This study proposes to include Landsat TM and AVIRIS mineral classification as a cost effective means for mapping the (largely) exposed surface mineralogy of the watershed and identifying source areas for naturally occurring Mercury containing minerals. Due to the extent of the Owyhee watershed, an initial assessment of tributary basins will be conducted using Landsat TM imagery to identify those tributary basins with geological and mineralogical anomalies related to mining and geologic formations associated with mercury. AVIRIS data will then be acquired over those specific watershed tributaries and the reservoir basin to identify specific suspected sources at the much higher spectral and spatial resolution of AVIRIS. The AVIRIS mapping will be used to develop land management plans and

reservoir watershed management alternatives to limit the amount of Mercury influent to the reservoir and to verify the validity of making direct remote measurements of water quality in the reservoir, in terms of total suspended solids and chlorophyll content.

Background:
Owyhee Reservoir was constructed during the 1930's by the Bureau of Reclamation, and covers approximately 13,900 acres over a lateral distance of 50 miles. Research projects and data collection activities have been limited. While anthropogenic Mercury source areas have been generally identified, very little is known regarding natural sources in the area. The Bureau of Reclamation is currently performing a baseline survey of Owyhee Reservoir for general chemistry and Mercury fate and transport. The reservoir study is evaluating the fate, transport, and transformation of Mercury in Owyhee Reservoir and inflow streams, and is interested in developing a more detailed knowledge of naturally occurring geologic Mercury source areas in the reservoir watershed. The natural and anthropogenic sources of Mercury in the watershed have produced Mercury bioaccumulation problems in local reservoirs, streams, and water bodies. Both Oregon and Idaho public health organizations have issued fish consumption advisories for Owyhee Reservoir, Antelope Reservoir, and several other watershed streams. The reservoir study is also evaluating the ability of AVIRIS to make remote water quality measurements through analysis of spectral characteristics associated with dissolved solids and amounts of chlorophyll present in the near-surface water layer.

Accomplishments:
An AVIRIS overflight was successfully completed in July, 1998 and the data were received in mid-1999. Field spectrometer ground calibration and water quality data were successfully collected with USGS Spectroscopy Laboratory and USBR Research Chemistry Laboratory cooperators. After receiving the data in late-1999 they were atmospherically corrected using ACORN (Atmospheric CORrection Now), a commercial off-the-shelf version of MODTRAN-4. A portion of the data over the reservoir was successfully georeferenced using field-collected control data (to +/- 1 pixel) allowing surface water quality measurements to be linked with corresponding pixels within the AVIRIS image. ACORN was again used to simulate TM spectra from the AVIRIS data, and the results were compared with chlorophyll & suspended solids data collected at the surface by both field spectrometer and chemical sampling during the AVIRIS overflight. Overall results of regression analysis produced an r^2 of 0.76 between AVIRIS and ground based water quality measurements. Methodology included determining best ways to compensate for sun glint on the reservoir surface, and experimentation with both unmixing and spectrum matching tools for mapping water quality measures. The study still plans to map rock mineralogy using continuum removal & spectrum matching tools within the USGS Spectroscopy Laboratory's Tetracorder algorithm. Field data will then be used to validate results.

Benefits realized to DOI land managers and study site partners:
If Mercury-rich volcanic source materials are successfully located and mapped, their contributions to reservoir Mercury levels might be more accurately quantified. Knowing where the sources are, managers may find new options for locally controlling, reducing, or diverting Mercury-laden runoff into the reservoir. As hyperspectral data becomes more available and less expensive (e.g. orbital sensors), this study has verified that hyperspectral imaging can be used directly or indirectly to routinely assess the health of reservoirs.

A significant outcome of this study was BOR's decision to acquire a full-range field spectrometer after seeing the demonstrated potential of imaging spectroscopy for assisting with research on developing remote water quality measures. The Bureau of Reclamation is now collecting spectra on other reservoirs in the western United States to simulate performance of airborne/orbital sensors. The USGS Spectroscopy Laboratory also benefited from this study by increasing their own experience in use of imaging spectroscopy for water quality measurements, while the BOR is learning about the capabilities of Tetracorder to identify and map mineralized features relating to the presence of Mercury.

Although this hyperspectral technical transfer project reached completion in early 2001, certain aspects of this study will continue throughout the year, and new studies based on the findings of this study will continue in years following.

Ultimately, both aspects of this study will benefit managers and users of reservoirs and surrounding lands as water quality is more frequently and accurately monitored.

Lessons learned:
Analysis and interpretation of the AVIRIS data obtained for this study underscored to the investigators how different the tools are from techniques applied to MSS data. Use of hyperspectral imaging (as well as collection of field spectra) was found to be of great value in predicting the potential performance of the other types of lower spectral resolution sensors for the specific applications of this study. There was a definite learning curve and investment of time and resources to implement the effective use of hyperspectral analysis tools. Because of their value, however, a significant investment was made in hardware (a full-range field spectrometer) and software (ENVI and ACORN) with the anticipation of expanding this work to make similar determinations (particularly with the water quality measurements) at other reservoirs.

5. Anticipated outcomes

The primary overall result of the NASA/DOI hyperspectral technical transfer project was the successful demonstration of AVIRIS hyperspectral imaging capabilities to land managing bureaus within the Department of the Interior for:

(1) Detection/mapping of multiple types of invasive plants
(2) Distinguishing eastern deciduous forest community types
(3) Demonstration of two remote measures of public reservoir water quality

All of the above confirmed the effectiveness of applying hyperspectral imaging technology to several timely and pertinent DOI land managing issues and problems. This potentially marks the early stages of a transition of hyperspectral imaging from a research-oriented technology to an applied land management tool. As a direct result of this project scientists within several DOI bureaus have acquired new knowledge and insights into some pragmatic land management applications of hyperspectral imaging technology.

As expected, the activities extending from this project gained broad public visibility through the project web site, which has been active for 3 years, and continues to be updated with results from each of the individual studies. Also, as hoped, increased dialog about the capabilities and potential applications of hyperspectral imaging has grown within and between each of the participating DOI bureaus, NASA, the USGS, and academic partners.

6. Unexpected outcomes and benefits

In addition to meeting most of the project objectives, some very significant outcomes resulted that went well beyond the initial expectations of the steering committee. These unexpected and beneficial outcomes occurred in the areas of (1) partnering, (2) science integration, (3) spawning of new, additional projects, and (4) substantial commitments/investments of project participants in hyperspectral imaging technology.

(1) Partnering: Although the project was intentionally designed to link DOI participants with experienced users of hyperspectral imaging technology, development of proposals submitted to the steering committee stimulated the formation of some broad alliances of scientists and natural resource managers between federal agencies and academia that otherwise might never have taken place. For example, the study at Theodore Roosevelt National Park brought a wide range of scientists together from NASA, the USGS, the USDA Agricultural Research Service, and the University of California at Davis. Similar alliances developed in related ways for each of the studies to some extent.

(2) Science integration: In a broad sense, this project brought federal as well as academic scientists together from many diverse specialties and disciplines, illustrating and underscoring the synergy that can result when individuals with many complementary backgrounds and skills are charged to work toward a common goal. More specifically, science integration took on particular meaning to project participants from the USGS. Coincidentally, within the same time frame as the hyperspectral technical transfer project, the USGS undertook a broad and ambitious re-organization with strong emphasis on integrating activities and functions of its four scientific disciplines: Geology, Mapping, Biology and Water. USGS scientists involved over the duration of this project represented three of the four USGS disciplines, and their activities and communications served as an early and successful demonstration of the purpose, spirit, and benefits of integrated science. These internal cross-disciplinary connections within the USGS have not only continued but have strengthened, underscoring the efficacy of the bureau's re-organization concept.

(3) Spawning of new, additional projects: In at least two of the four studies undertaken in this project additional research projects have resulted. For example, success of water quality measurements by the Bureau of Reclamation at Owyhee Reservoir has lead to the BOR deciding to pursue similar work at other reservoirs under their jurisdiction. The study to detect/map leafy spurge at Theodore Roosevelt National Park led to another NASA-sponsored study to compare AVIRIS data with orbital imaging spectrometer data from the EO-1 Hyperion sensor as part of the EO-1 Science Validation Team. A second new leafy spurge study was sponsored by the USDA Agricultural Research Service as part of TEAM Leafy Spurge to demonstrate and validate regional methods for remote detection and mapping. Two Ph.D. studies also resulted as further ramifications of the initial leafy spurge investigation. The first is developing an expert system model to predict locations of future leafy spurge infestations, and the second is using data from AVIRIS missions two years apart to determine changes in leafy spurge distributions in connection with biological and

chemical control measures undertaken by the park. Another Master's thesis project will interpret the 1999 AVIRIS data over Theodore Roosevelt NP to develop fire fuel models, and yet another scientist from the USGS will analyze the 1999 AVIRIS data at the park for extracting locations of burnable coal seams. The original investigation team at Theodore Roosevelt NP had no way of anticipating the degree of interest and variety of research opportunities that would be generated from the NASA sponsored AVIRIS missions resulting from the original technology transfer study.

(4) Investments in the technology: Each of the four studies resulted in participants making investments in hyperspectral imaging technology, to one extent or another. The National Park Service, in response to both the Congaree Swamp study and the Theodore Roosevelt study invested in hyperspectral imaging software and ongoing maintenance for use by their project participants. Partly as a result of early success in leafy spurge detection/mapping, the USDA Agricultural Research Service made a major decision to invest in a complete hyperspectral imaging system (a Compact Airborne Spectrographic Imager), a full-range field spectrometer, and hyperspectral imaging software. The Bureau of Reclamation also purchased a full-range field spectrometer in support of its decision to use imaging spectroscopy for making water quality measurements in several more reservoirs under its jurisdiction. The BOR also purchased hyperspectral imaging software, and tools based on NASA's MODTRAN-4 for atmospheric correction – ACORN (Atmospheric CORrection Now). The USGS, after starting yet another project to use hyperspectral imaging to enhance the mapping of fire fuels also decided to purchase a full-range field spectrometer, and obtained funds to support an AVIRIS mission over Yosemite National Park. The USGS also purchased four additional licenses for hyperspectral image processing and ACORN calibration software. These levels of commitment to hyperspectral imaging tools were not anticipated by the original study, but they clearly demonstrate the degree to which participants literally bought into the technology, underscoring the success of the original technology transfer project.

7. Summary

The joint partnering effort between NASA and the USGS to demonstrate and transfer the technologies related to hyperspectral imaging to DOI bureaus were largely successful in the context of the envisioned project goals. Although the project itself was conceived and implemented in a partnering environment, the additional integration and collaborations that resulted went far beyond initial project expectations. USGS re-organizational vision and goals for future science directions were reinforced in a beneficial time-coincident manner, and internal connections between individual scientists and bureau disciplines were enhanced. Participants from all projects made ongoing commitments to the technology ranging from obtaining hyperspectral imaging software to procuring entire ground and aerial data acquisition systems. In two instances, study participants are continuing their work through partnering efforts, and by providing their own resources and support.

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